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EFFECT OF ELECTRON RADIATION ON TV LENS COMPONENTS

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SUMMARY

Optical glasses similar to those which will be used as lens materials in the TV camera system of the Nimbus satellite were exposed to 1- and 2-Mev electrons to determine the effect of electron bombardment on their optical properties. The electron flux used was 4.5×10^{11} electrons/cm^2-day which approximates the orbital environment of the satellite. Results indicated a significant reduction in the optical transmissivity of the glasses during exposure. However, it was found that damage to the glass could be significantly reduced with the use of a protective cover-plate made from radiation resistant fused silica.

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INTRODUCTION

Orbiting scientific satellites containing optical systems such as television, telescopes, and star trackers will be required to operate for considerable periods of time in a radiation environment. This environment will consist primarily of electrons and protons which make up the Van Allen belts. It has been observed that x and gamma radiation produce color absorbing defects in glass which decrease the amount of light transmitted by the glass. Because the glass elements of an orbiting optical system will generally be on the surface of a satellite, the glass will be exposed to direct bombardment by electrons. It then becomes important to determine whether electron irradiation has the same effect on glass as does x and gamma radiation and, if so, to determine what effect this irradiation has on the actual performance of the optical system. This paper describes the effect that electron radiation has on the transmissivity of a television lens system which was designed for use on a Nimbus weather satellite.

RADIATION EXPOSURE

The radiation levels to which the TV lens was exposed simulated as closely as possible the actual radiation environment to which the Nimbus satellite would be exposed in its orbit through the Van Allen belt. Based on an altitude of 800 Km (500 mi) in a circular orbit inclined 90° to the equator, the initial value of electron flux was calculated as 6×10^{12} electrons/cm^2-day. After this test had begun, more complete information on the radiation flux in the orbit was made available and the value was corrected to 4.5×10^{11} electrons/cm^2-day*.

The electron energies in this orbit range from 0.5 Mev to 8 Mev, however, 45% of the electrons have energies between 0.5 Mev and 2 Mev and a total of 85% have energies less than 3 Mev. From these figures, it was believed that electron energies of 1 Mev and 2 Mev would include the major

*Private communication from G. Strassinopoulos, Goddard Space Flight Center.

portion of electrons that would bombard the satellite and, therefore, irradiation was performed at these energies, with most of the work done at 2 Mev. All irradiation was done at room temperature in air. The time required for irradiation varied from 55 seconds for 1-Mev electrons to 27 seconds for 2-Mev electrons. This exposure was equivalent to that received by the satellite in two days.

PROCEDURES

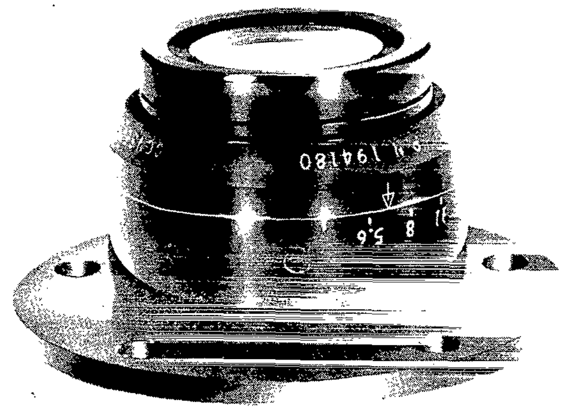

Figure 1—Experimental TV lens system.

The lens system used in this study is shown in Figure 1. It consists of a series of glass lenses cemented together in an aluminum frame. The first glass element in the lens system was *dense barium crown* and was followed by *extra dense flint glass*. Since the lens assembly was cemented together and could not be dismantled for examination of the individual elements, the entire lens system was irradiated and transmissivity measurements were made on the integral unit.

Transmissivity measurements before irradiation and after each exposure were made on the lens system by use of a Cary recording monochrometer. Measurements of transmissivity versus wavelength were continuously recorded for wavelengths between 5400Å and 6400Å. Due to the focusing effect of the lens which prevented all of the transmitted light from reaching the photomultiplier tube of the instrument, some modifications in measuring procedures were necessary. Using this modification, transmissivity versus wavelength curves were obtained which, while not giving an absolute value of transmissivity, could be compared with previous curves similarly obtained and changes in transmissivity with radiation could be determined.

Exposure of the lens to 1-Mev electrons resulted in an appreciable decrease in transmissivity. The total loss in transmissivity after electron exposure equivalent to eight days in orbit was 47%. For ease in presentation, one particular wavelength (6100Å) was picked and the data showing the loss in transmissivity versus exposure is presented in Table I. The values are plotted in Figure 2.

Table 1

Exposure (Days) vs % Change in Transmission.

Exposure (Days)	Relative Transmissivity (at 6100Å)	% Change
0	31	---
2	22.4	27.8
4	19.5	37.1
6	17.4	43.9
8	16.4	47.1

The rate of loss in transmissivity which was quite rapid initially became less rapid after the second exposure (4 days) and leveled off with increasing exposure. After transmissivity measurements were made following

the final exposure (8 days), the entire lens system was annealed at 85°C for 63 hours. Transmissivity measurements made after this annealing period showed that substantial recovery had occurred in the lens (Figure 2).

To determine the effects of higher energy electrons, the annealed lens was exposed to 2-Mev electrons. The flux used was the same (6×10^{12} electrons/cm^2-day) and the total exposure was equivalent to 2 days in orbit. The results of post-irradiation transmissivity measurements indicated a reduction in transmissivity of 42% (Figure 2).

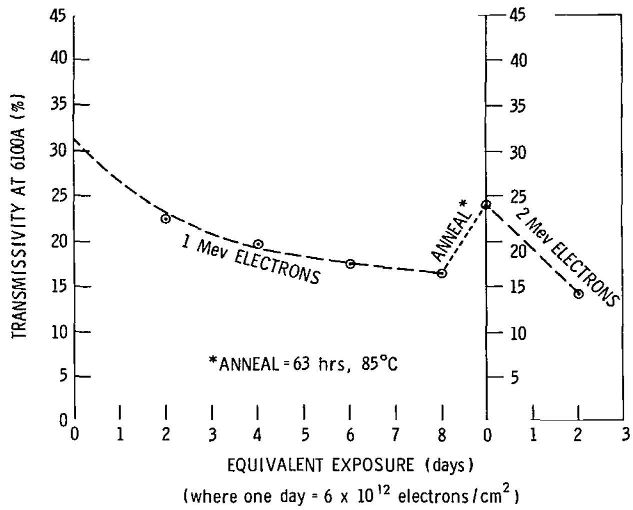

Figure 2—Nimbus TV lens system transmissivity versus electron exposure.

In order to prevent radiation damage to the lens system, a 0.205-inch thick optically flat piece of radiation resistant fused quartz was installed over the front of a new lens system. This thickness of fused quartz was chosen because calculations on the range of 2-Mev electrons indicated that a 0.2-inch thick coverplate would be sufficient to prevent most electrons from penetrating this protective cover. The entire lens system was then exposed to electron radiation. The energy of the electrons was 2 Mev and the flux used was the corrected value of 4.5×10^{11} electrons/cm^2-day. The total exposure was equivalent to 140 days in orbit. Absolute transmissivity measurements were made on this lens system by the National Bureau of Standards before and after radiation exposure. Results, tabulated in Table 2 show a loss in transmissivity of 8.4% after 140 day exposures. Transmissivity measurements were made with "white light" over the entire visible portion of the spectrum and were performed in accordance with MIL-STD-150A, section 3.2

Table 2

Transmissivity for Lens with Fused Quartz Coverplate.

Transmissivity	
Before	After
88.3%	79.9%

To determine the amount of protection the fused quartz coverplate provided the lens components, one additional test was performed. The mock lens system shown in Figure 3 was fabricated. The system consisted of a hollow aluminum cylinder containing three optically flat glass plates arranged in series behind the fused quartz coverplate. The components were made from dense barium crown glass and extra dense flint glass. Three sets of glass elements were made, the only difference in the sets was in the thickness of fused quartz used for the coverplate. The unit was designed to be dismantled easily so that after each radiation exposure an accurate optical density measurement could be made on each optical element. The thickness of the fused quartz was 0.205 inch, 0.131 inch and 0.065 inch. Optical measurements were made after exposures equivalent to 2, 4, 6, 8, 12 and 16 days in orbit. The flux used was 4.5×10^{11} electron/cm^2-day and the electron energy was 2 Mev.

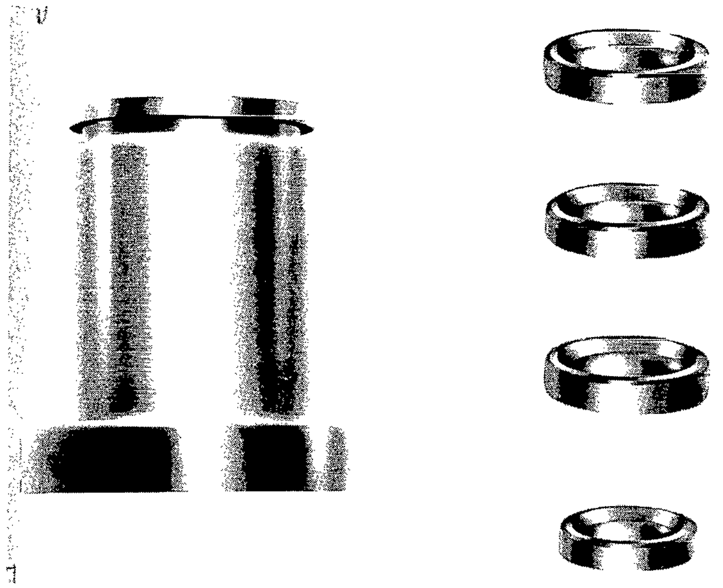

Figure 3—Mock lens used to determine protective effects of a fused quartz coverplate.

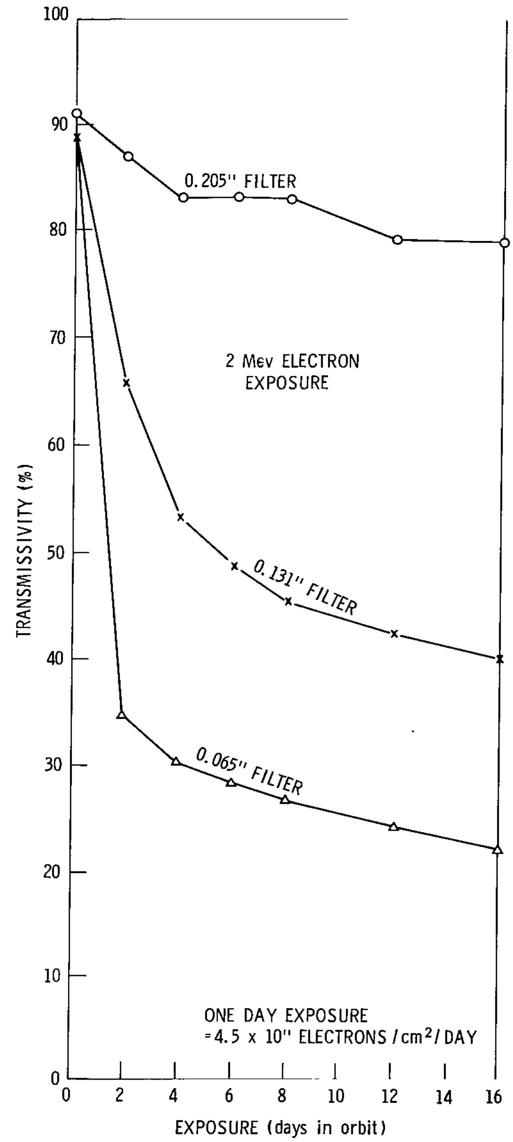

Figure 4—Transmissivity loss in fused-quartz protected lenses.

Results of the test showed no significant change in the transmissivity of the fused quartz regardless of its thickness. There was, however, considerable loss in transmissivity of the glass elements directly behind the 0.131-inch and the 0.065-inch thick fused quartz coverplates (see Figure 4). Some loss in transmissivity was noted in the glass element directly behind the 0.205-inch thick fused quartz coverplate; however, the loss was considerably less than that which occurred in the other two similarly located elements. The maximum loss in transmissivity occurred in the glass element directly behind the 0.065-inch thick fused quartz coverplate. The transmissivity in this element was reduced from an initial value of 91.2% to 22% after an exposure equivalent to 16 days. The transmissivity of the glass element behind the 0.131-inch thick fused quartz coverplate was reduced from 89.1% to 40.7% with similar exposure. Some loss in transmissivity was noted in the second and third glass elements behind the fused quartz plate. The maximum loss in transmissivity for these elements was 11% after 16 day equivalent exposure. This loss was noted in the second element behind the 0.065-inch fused quartz plate. The loss in transmissivity for all the remaining elements was less than the above values.

After the final electron exposure, the glass elements were allowed to remain at room temperature. Transmissivity measurements were taken at intervals of 1.5 hours, 17 hours, and 4 days. Results plotted in Figure 5 show a marked recovery in all specimens.

CONCLUSIONS

Results of these tests have shown that the optical glass intended for use as lenses in a television camera on a weather satellite was significantly affected by 1 and 2-Mev electron radiation. The transmissivity of these lens components was reduced to such an extent that their usefulness in a workable satellite is doubtful. The amount of damage (loss in transmissivity) is apparently directly related to the amount of electron exposure. An examination of Figures 2 and 4 indicates that the amount of damage increases quite rapidly with increased exposure. However, it appears that the amount of damage reaches some specific level and changes very little with future exposure.

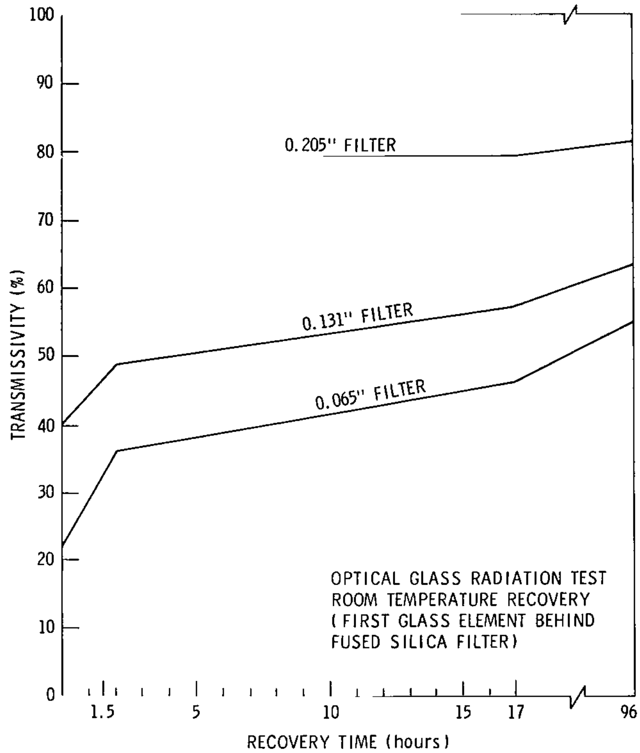

Figure 5—Transmissivity recovery following electron exposure.

It must be remembered that the results from the first series of tests on the actual lens system cannot be compared with those from the mock lens system in absolute values. The conditions of the tests, the exposure levels, and the method of obtaining optical transmission values were different in each case. However, the general effects of the radiation on the glass in both tests were similar and can be related.

It was found that considerable radiation protection for the lens system could be provided by incorporating a radiation resistant fused quartz coverplate over the lens. It was further shown that significant radiation damage occurred only in those lenses directly behind a coverplate less than 0.205-inch thick. Although calculations indicated the range of 2-Mev electrons in fused quartz to be 0.137 inch, some slight damage to the glass behind the 0.205-inch thick coverplate did occur. This damage probably resulted from electron straggling* (see Reference 1) which allowed some finite number of electrons to penetrate the coverplate and interact with the glass elements. As was expected, considerably more damage occurred in the glass behind the thinner coverplate. Some additional damage could be expected in glass behind the 0.205-inch thick coverplate in a true space environment due to the presence of some higher energy electrons.

One rather significant observation noted was the rapid recovery exhibited by all the lens elements as a result of annealing even at room temperature. Since the lens is exposed to electron bombardment at a much lower rate in orbit than in the laboratory, it might recover a significant percentage of the damage nearly as rapidly as damage occurs. This would

*Evans, R. D., *The Atomic Nucleus*. New York: McGraw-Hill Book Company, 1955, pp 621-623.

result in only a very slow increase in damage with time. These theories would require further study.

It is believed that whether recovery in orbit occurs or not, it would be unwise to ignore the fact that damage to the glass elements can occur as a result of exposure to electron radiation. It is also believed that to increase reliability by either incorporating a radiation resistant coverplate or the use of radiation resistant glass for the lens elements would not be extravagant.

ACKNOWLEDGMENTS

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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